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Preliminary Report -

EFFECTS OF DECREASING THE AIR TEMPERATURE RISE DURING THE ON-CYCLE OF A BURNER IN A FORCED AIR DOWNDRAFT TOBACCO STICK-KILN

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ABSTRACT The volume of natural gas entering the burner of a downdraft stick-kiln was reduced to decrease the rise in air temperature during the on-cycle of the burner. The objective was to prevent green fixation and reddening of the tobacco in the upper tiers of the downdraft stick-kiln. Results indicated that the rise in air temperature was significantly reduced by decreasing the fuel input to the burner, however, cured tobacco quality was not improved. As compared to cures in a control kiln, reducing the fuel input to the burner in the test kiln did not significantly effect fuel consumption in the first two cures, however, 10% more fuel was consumed during the third cure. Monitoring will be continued during the 1987 curing season.

BACKGROUND INFORMATION

The volume of fuel entering the burner of a forced-air, downdraft tobacco stick-kiln is independent of the temperature setting. A constant volume of fuel enters the burner to maintain air temperatures ranging from 25°C to 70°C, however, the length of firing or the on-cycle of the burner is considerably longer in duration as the temperature setting is increased.

During the 1985 curing season, the Agricultural Energy Centre monitored the fluctuation in air temperature during the on/off cycles of a 790 MJ/h oil-burner in a low-profile, forced-air, downdraft tobacco stick-kiln. Air temperatures were recorded with unprotected thermocouples positioned centrally in the air delivery plenum of the downdraft kiln. The results of the monitoring are represented graphically in figure I. The upper line of the graph indicates the maximum air temperatures recorded during the on-cycle of the burner, while the lower line represents the minimum air temperatures recorded during the off-cycle of the the burner. The line between the upper and lower lines indicates the average air temperature recorded during each hour of the cure.

Monitoring of the cure during the yellowing phase indicated that the temperature rise of the air during the on-cycle of the burner was significantly greater than the minimum and average air temperature. During each on-cycle of the burner, the air temperature was increased 11 - 14 C°. As compared to the average air temperature, the maximum air temperature was 8 - 12 C° higher. The average air temperature per hour during the yellowing phase of the cure was slightly greater than the minimum air temperature since the duration per hour of the on-cycle was quite short. During the colour fixing phase of the cure, the air temperature was increased 9 - 13 C° during each on-cycle of the burner. As compared to the average air temperature, the maximum air temperature was 4 - 8 C° higher. The duration per hour of the on-cycle was longer during the colour fixing phase than during the yellowing phase of the cure. The average air temperature per hour was similar to the mean air temperature during

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The mention of manufacturers trade names is for the purpose of specific product description and does not indicate endorsement of criticism of that product or products not mentioned by the authors of the Ontario Ministry of Agriculture and Food.

the on-and off-cycles of the burner. During the final drying phase of the cure, the air temperature was increased 9 - 12 C°. As compared to the average air temperature per hour, the maximum air temperature was 4 - 8 C° higher. Again, the average air temperature per hour was similar to the mean air temperature during the on-and off-cycles of the burner.

Temperatures recorded during the yellowing phase of the cur indicate that the tobacco in the upper tiers of a downdraft kiln is exposed to temperatures which could cause green fixation. During the yellowing phase, the tobacco must be kept alive to allow chemical changes to occur. This permits the colour of the tobacco to change from green to yellow. If the air temperature exceeds 40.6°C before the tobacco has turned yellow, green fixation can occur (Anon, 1969). During the yellowing phase of the cure monitored, the maximum air temperature exceeded 40.6° by 11 C° after 24 hours of the cure. During the remainder of the yellowing phase, which was not completed for another 67 hours, the upper tiers of tobacco were exposed to air temperatures 8 - 11 C° higher than 40.6°C.

Another interesting observation can be drawn from the drying phase of the cure monitored. During the final drying phase, tobacco will redden in appearance if exposed to an air temperature of 76.7°C or greater (Anon, 1969). During the final drying phase of the cure monitored, the maximum air temperature reached 77°C during the on-cycle of the burner from 200 h to 221 h of the cure.

Green fixation and reddening of tobacco are most pronounced in the upper 2 or 3 tiers of tobacco in a downdraft stick-kiln. It is thought that these curing problems are partially caused by wide fluctuations in air temperature during the on/off cycle of the kiln's burner. Green fixation and reddening may possibly be prevented by reducing the wide fluctuation in air temperature. One method of reducing the large rise in air temperature during the on-cycle of the burner is to reduce the volume of fuel entering the burner. This may also have a positive effect on the fuel consumption per cure.

OBJECTIVES

Reducing the volume of fuel entering the burner of a downdraft kiln allowed the following to be observed:

1/ fluctuation in air temperature during the on/off cycles of the burner;

2/ effects on curing process and tobacco quality;

3/ fuel consumption per cure.

PROJECT DESIGN

Test Site In cooperation with tobacco producer, Mike Bokla, R. R. # 2, Delhi, a test site was selected on his family's farm. Two high profile, forced-air, downdraft tobacco stick-kilns were selected. Both kilns were of relatively tight construction. Urethene foam lined the interior of the roof and cracks in the foundation of both kilns. Each kiln was equipped with a "Balthes N-750" burner unit fuelled by natural gas. The gas input of each burner was rated at 790 MJ/h at a manifold pressure of 2.1 kPa.

Comparative Testing One kiln was selected as the "test" kiln while the other kiln served as the "control" kiln. As illustrated in figure II, the volume of gas flowing into the burner of the test kiln was reduced manually by throttling the valve between the gas solenoid valve and the burner. The degree of throttling was dependent upon the desired air temperature. A stem valve was fitted into the gas line between the valve that was being throttled and the burner. A pressure gauge was connected to the stem valve to determine the amount of gas entering the burner when the valve was being throttled.

MONITORING

The test kiln and control kiln were loaded on adjacent days. This particular loading pattern reduced the variability of tobacco maturity and the difference in ambient air temperature between the cures in each kiln. The cooperator used his own judgement in selecting each kiln's curing schedule.

The following parameters were monitored during each cure in the test and control kilns:

Temperature Type K thermocouples were positioned centrally in air delivery plenum of each kiln. A "Digi-Sense Type K", digital temperature indicator was used to measure the minimum and maximum air temperatures during the on/off cycles of the burner. A liquid-in-glass thermometer was positioned between the second and third tiers of tobacco near an inspection door in the upper portion of each kiln. The thermometer was used to measure the air temperature below the upper tiers of tobacco.

Fuel Energy Input A time-clock was connected in series to the burner relay of each kiln to determine the duration of the on-and off-cycles of the burner. "Rockwell RC-415" natural gas meters were used to calculate the fuel energy consumption of the burner in relation to the time recorded by the clock. The gas meters were also used to determine the total fuel consumed per cure.

Mass of Cured Tobacco The cooperator recorded the mass of tobacco cured and the grade index of the cured tobacco prior to marketing.

General Data The cooperator recorded general weather observations and any unusual occurrences during each cure.

RESULTS

During the harvest season three sets of cures were monitored. Seconds, fourths and under-tips were cured in the first, second and third cures of each kiln, respectively.

Minimum and Maximum Air Temperatures During Cycling of the Burner

Decreasing the volume of gas flowing into the burner significantly reduced the rise in air temperature during the on-cycle of the burner. Figures III, IV and VI illustrate the air temperatures measured during the on-and off-cycles of the burner in the test kiln during the first, second and third cures, respectively. Figures V and VII illustrate the air temperatures measured during the on-and off-cycles of the burner in the control kiln during the second and third cures, respectively. Air temperatures during the on/off cycles of the burner in the control kiln during the first cure were not recorded.

In figure III, the rise in air temperature during the on-cycle of the burner in the test kiln ranged from 3 C° during the initial stages of the yellowing phase to 10 C° during the latter stages

of the final drying phase. Assuming that the temperature measurements with the liquid-in-glass thermometer represent the constant air temperatures during the on/off cycles of the burner, the maximum air temperature during the yellowing phase exceeded the thermometer reading of 40.6°C for approximately 16 hours. During this period, the maximum air temperature reached as high as 43.9°C. During the final drying phase, the maximum air temperature exceeded 76.7°C for approximately 11 hours. During this period, the maximum air temperature reached as high as 77.2°C.

As illustrated in figure III, the temperature rise of the air during the on-cycle of the burner increased as the gas pressure was increased. The gas pressure during the yellowing phase varied between 0.1 - 0.5 kPa and was gradually increased to 2.1 kPa during the final drying phase.

Figures IV and VI illustrate the fluctuation in air temperature during the on/off cycles of the burner in the test kiln during the second and third cures, respectively. During the second and third cures, the gas pressure during the yellowing phase was set at 0.1 - 0.7 kPa and was gradually increased to 2.1 kPa during the final drying phase. In the second cure, the fluctuation in air temperature ranged from 4 C° during the initial stages of the yellowing phase to 12 C° during the latter stages of the final drying phase. The maximum air temperature during the yellowing phase exceeded the thermometer reading of 40.6°C for approximately 32 hours. During this period, the maximum air temperature reached as high as 44.4°C. During the final drying phase, the maximum air temperature exceeded 76.7°C for approximately 10 hours. During this period, the maximum air temperature reached as high as 80.6°C. In the third cure, the fluctuation in air temperature ranged from 3 C° during the initial stages of the yellowing phase to 12 C° during the latter stages of the final drying phase. The maximum air temperature during the yellowing phase exceeded the thermometer reading of 40.6°C for approximately 8 hours. During this period, the maximum air temperature reached as high as 43.3°C. During the final drying phase, the maximum air temperature exceeded 76.7°C for approximately 15 hours. During this period, the maximum air temperature reached as high as 79.4°C.

In the control kiln, the gas pressure setting remained constant at 2.1 kPa. As illustrated in figure V, the largest fluctuation in air temperature during the second cure in the control kiln was recorded during the yellowing phase. The temperature rise of the air ranged from 14 C° to 22 C° during the entire cure. The maximum air temperature during the yellowing phase exceeded the thermometer reading of 40.6°C for approximately 65 hours. During this period, the maximum air temperature reached as high as 56.1°C. During the final drying phase, the maximum air temperature exceeded 76.7°C for approximately 54 hours. During this period, the maximum air temperature reached as high as 88.3°C.

The temperature rise of the air during the third cure in the control kiln was similar to the second cure in the control kiln. As illustrated in figure VII, the temperature rise of the air ranged from 14 C° to 20°C during the entire cure. The maximum air temperature during the yellowing phase exceeded the thermometer reading of 40.6°C for approximately 48 hours. During this period, the maximum air temperature reached as high as 57.2°C. During the final drying phase, the maximum air temperature exceeded the thermometer reading of 76.7°C for approximately 30 hours. During this period, the maximum air temperature reached as high as 88.3°C.

Fuel Energy Input of Burner Figure VIII summarizes the duration of the burner on-cycle and the fuel energy input of the burner during the three sets of cures in the test and control kilns. The fuel energy input to the burner in the test kiln during the three cures ranged from 259 MJ/h at maximum gas throttling to 640 MJ/h at a manifold pressure of 2.1 kPa. During the three cures in the control kiln, the fuel energy input to the burner was constant at 792 MJ/h at a manifold pressure of 2.1 kPa. It is worthwile noting that at a gas pressure of 2.1 kPa the fuel energy input to the burner in the test kiln was 152 MJ/h less than the fuel energy input to the burner in the control kiln. This explains why the air temperature rise during the final drying phase in the test kiln was not as large as in the control kiln. Even though the orfices of the burners were of the same size, the orfices of the burner in the test kiln must

have been dirty which restricted a portion of the gas flow and reduced the heat output of the burner.

The duration of the burner on-cycle during the yellowing phase of cures in the test kiln was considerably longer as compared to the yellowing phase of cures in the control kiln. The duration of the burner on-cycle in the test kiln ranged from 13 minutes per hour to 29 minutes per hour whereas in the control kiln the duration of the burner on-cycle ranged from 5 minutes per hour to 9 minutes per hour. Decreasing the fluctuation in air temperature during the yellowing phase of cures in the test kiln appears to have affected the time required to yellow the tobacco. The yellowing phase of cures in the test kiln as compared to cures in the control kiln were decreased by 9 hours, 14 hours and 11 hours during the first, second and third set of cures, respectively.

The duration of the on-cycle during the colour fixing and final drying phases in the test kiln ranged from 17 minutes per hour to 37 minutes per hour as compared to 18 minutes per hour to 29 minutes per hour in the control kiln. As compared to the control kiln, decreasing the fluctuation in air temperature during the colour fixing and final drying phases of cures in the test kiln did not significantly affect the duration of the two curing phases during the first and third cures. The only significant difference was between the second cures in the test and control kilns. The colour fixing and final drying phase was 8 hours less in the test kiln than in the control kiln.

Fuel Consumption Per Cure Figure IX summarizes the fuel energy consumption of the three cures in each kiln. The results from the first set of cures indicate that the test kiln consumed 37.1 MJ/kg of cured tobacco while the control kiln consumed 37.7 MJ/kg of cured tobacco. This represents a 1.6% difference in fuel consumption in favour of the test kiln. Results from the second set of cures indicate that the test kiln consumed 24.7 MJ/kg of cured tobacco while the control kiln consumed 25.1 MJ/kg of of cured tobacco. Again, this represents a 1.6% difference in fuel consumption in favour of the test kiln. Results from the third set of cures indicate that the test kiln consumed 19.4 MJ/kg of cured tobacco while the control kiln consumed 17.6 MJ/kg of cured tobacco. This represents a 10.2% difference in fuel consumption in favour of the control kiln.

Length of Cure Over three cures in the test kiln, the duration of the cures averaged 166 hours. In the control kiln the duration of the three cures averaged 180 hours. It can be assumed that the shorter curing time in the test kiln was a result of decreasing the fluctuation in air temperature during the on/off cycles of the burner.

Tobacco Quality Tobacco cured in the test and control kilns was divided into four grades by the cooperator: bright, dark, green and red. Figure X is a summary of each grade. The overall quality of tobacco cured in the test kiln was poorer than tobacco cured in the control kiln. Tobacco grades from cures in the test kiln as compared to cures in the control kiln had 13% less bright, 11% more dark, 4% more green and ½% less red. The grades recorded by the cooperator indicate that the cured tobacco quality was not improved by decreasing the temperature fluctuation during the on/off cycles of the burner, however, it is not known if the maturity of the tobacco cured in the test kiln was comparable to that cured in the control kiln.

SUMMARY

1/ During the yellowing phase of the cures in the test kiln, the fuel energy input of the burner was reduced to 259 - 339 MJ/h. This resulted in an air temperature rise of 3 C° to 7 C° during the on-cycle of the burner. The maximum air temperature reached as high as 44.4°C. As compared to cures in the control kiln, the air temperature rise during the yellowing phase ranged from 14 C° to 21 C° during the on-cycle of the 792 MJ/h burner. The maximum air temperature reached as high as 57.2°C.

2/ During the final drying phase of the cures in the test kiln, the fuel energy input of the burner ranged from 624 - 640 MJ/h. This resulted in an air temperature rise of 8 C° to 12 C°. The maximum air temperature reached as high as 80.6°C. As compared to cures in the control kiln, the air temperature rise during the final drying phase ranged from 18 C° to 22 C° during the on-cycle of the 792 MJ/h burner. The maximum air temperature reached as high as 88.3 C°.

3/ During the yellowing phase of the cures in the test kiln, the maximum air temperature exceeded 40.6°C for 8h to 32 h. During the yellowing phase of the cures in the control kiln, the maximum air temperature exceeded 40.6°C for 48 h to 65 h.

4/ During the final drying phase of the cures in the test kiln, the maximum air temperature exceeded 76.7°C for 10 h to 15 h. During the final drying phase of the cures in the control kiln, the maximum air temperature exceeded 76.7°C for 30 h to 54 h.

5/ During the yellowing phase, the on-time of the burner operating at 259 - 339 MJ/h was 8 - 20 minutes per hour longer than the on-cycle of the 792 MJ/h burner. During the colour fixing and final drying phase a fuel input of 339 - 640 MJ/h increased the on-time of the burner by as much as 8 minutes per hour as compared to a burner operating at 792 MJ/h.

6/ The duration of the cures in the test kiln were shortened by an average of 14 hours as compared to cures in the control kiln.

7/ Reducing the volume of natural gas entering the burner did not improve cured tobacco quality.

8/ Gas consumption data indicated that reducing the fuel input of the burner in the test kiln conserved 1.6% in fuel over the first two cures, however, a 10% fuel loss was realized during the third cure.

RECOMMENDATIONS

1/ Monitoring should be continued during the 1987 curing season to verify the results from the 1986 curing season.

ACKNOWLEDGEMENTS

The authors extend their thanks to Mike Bokla for his suggestions and excellent cooperation.

REFERENCES

Anon, 1969. Curing flue-cured tobacco. Agriculture Canada, Ottawa, Canada. Publication 1312.

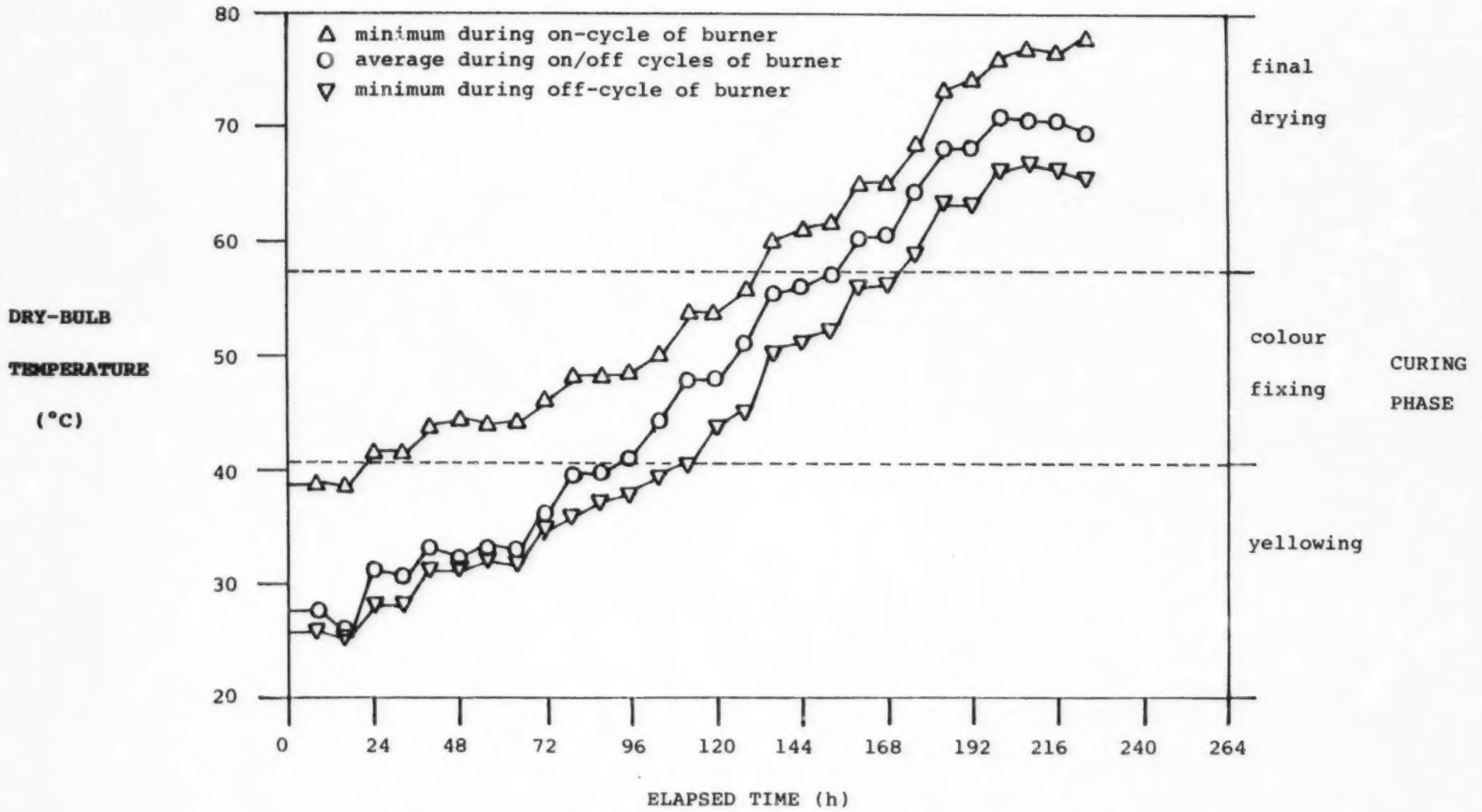

Figure I: Air Temperatures During Burner Cycling

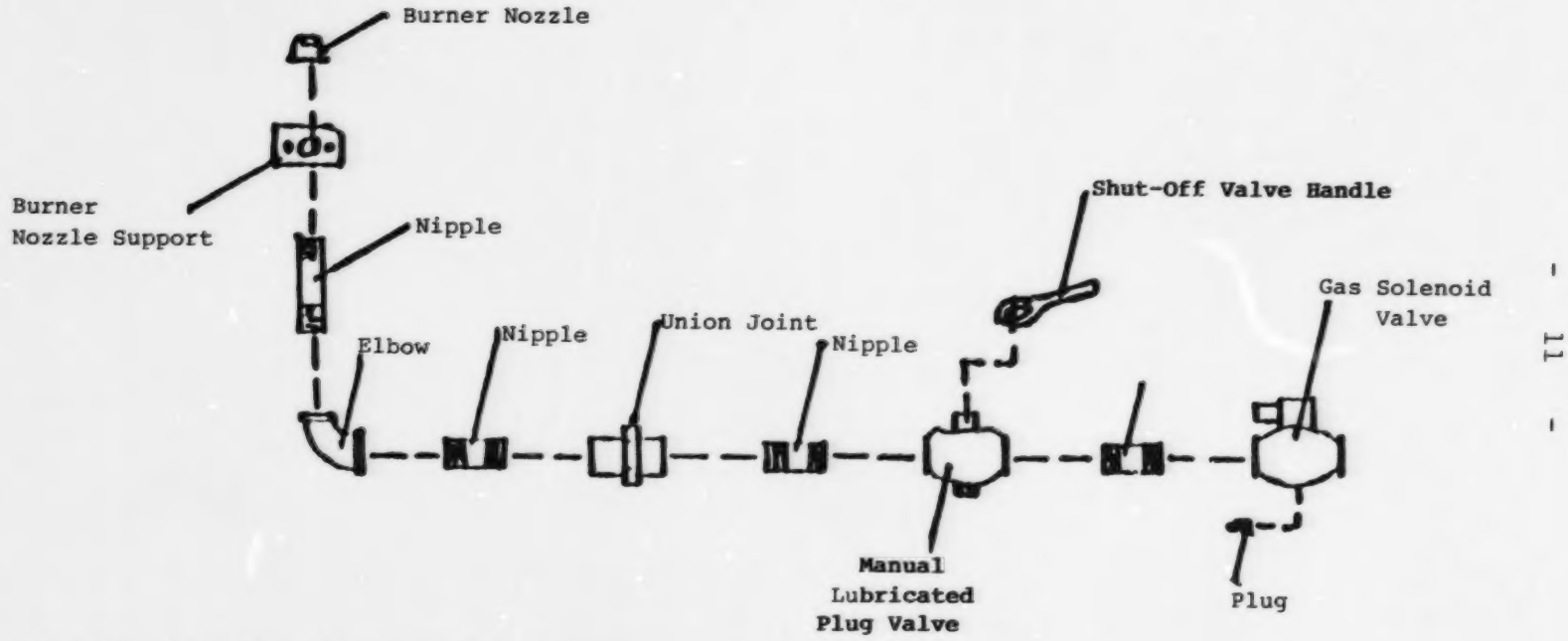

Figure II: Gas Line Assembly, "N-750 Balthes Burner"

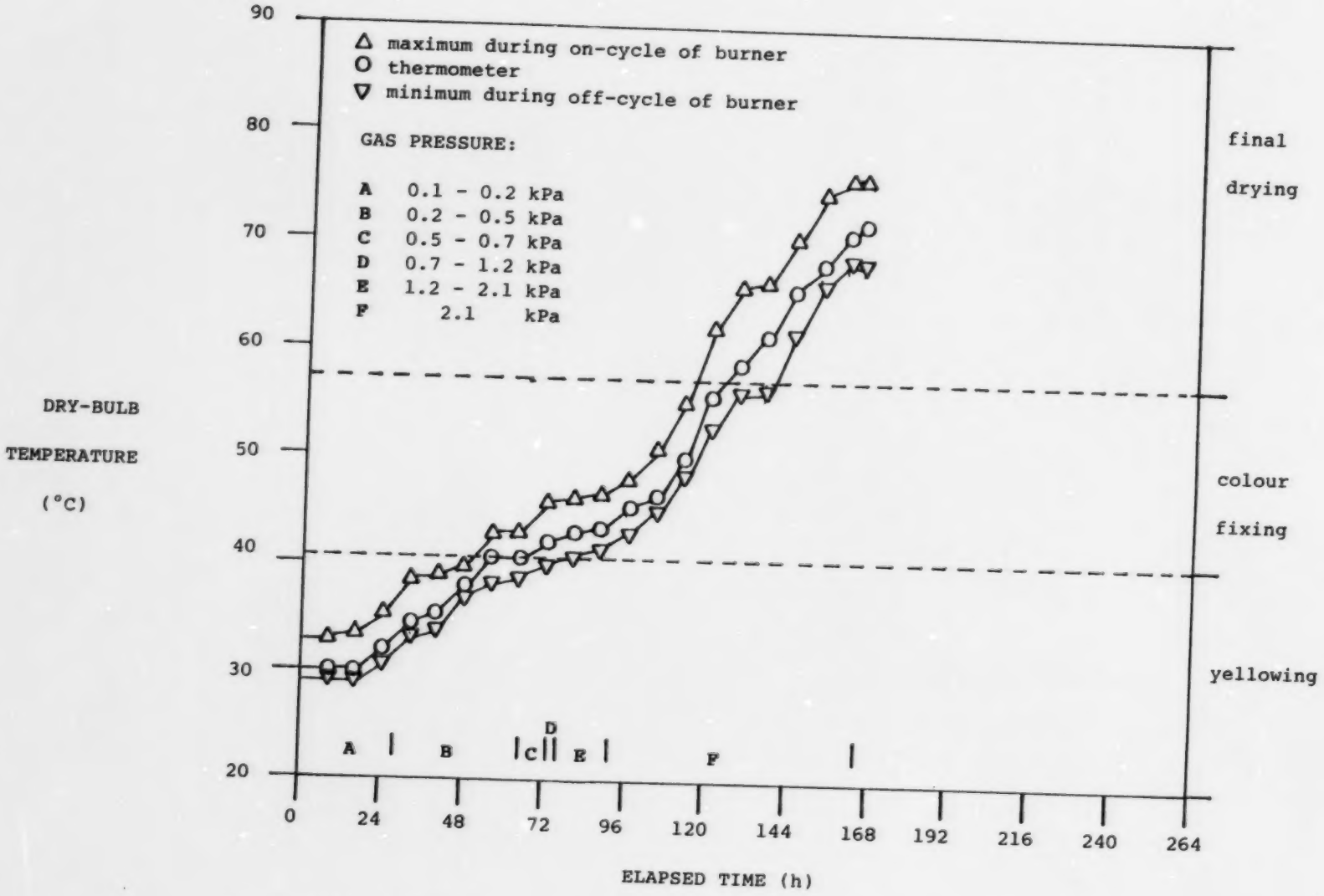

Figure III: Temperature History - Cure I Test Kiln

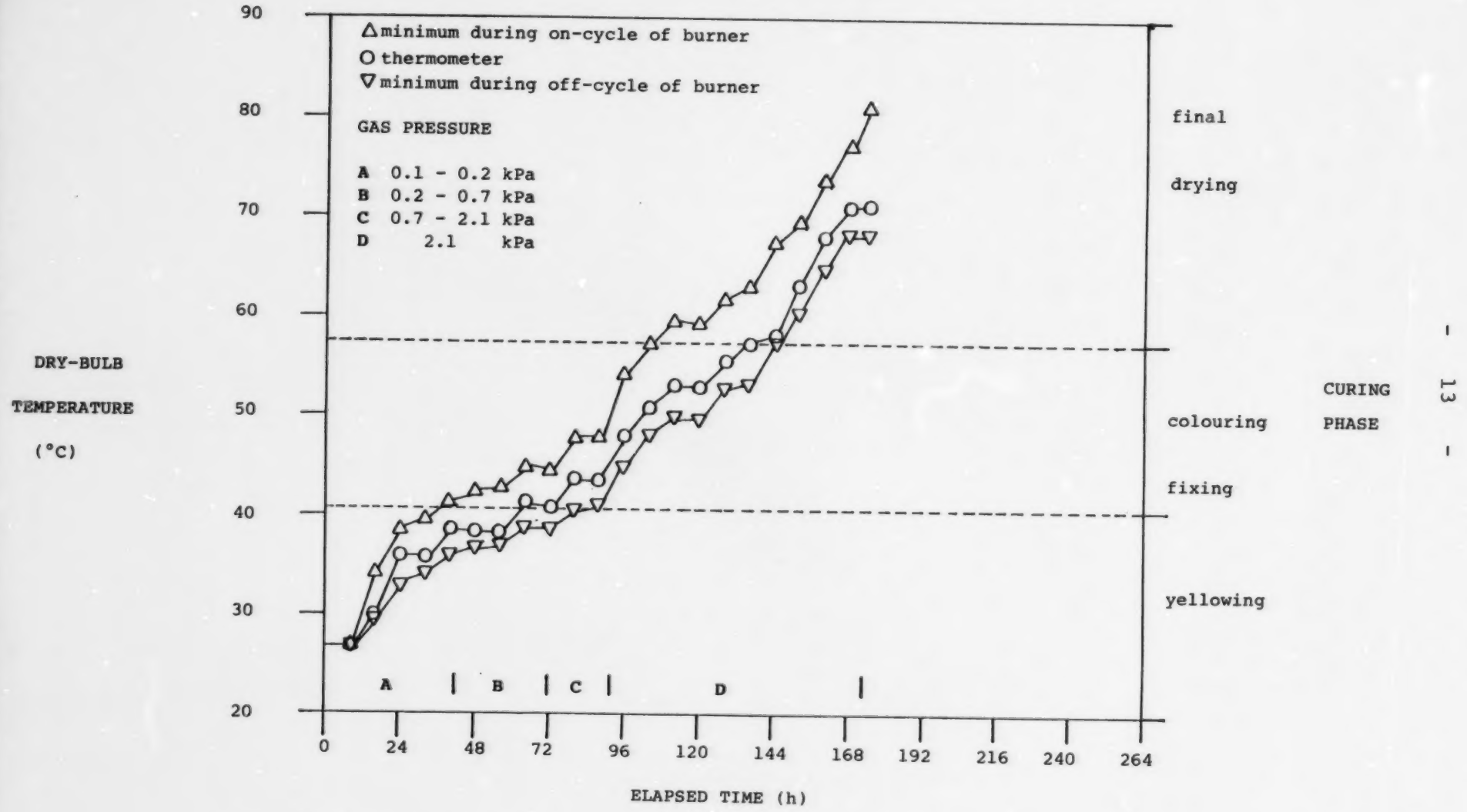

Figure IV: Temperature History - Cure II Test Kiln

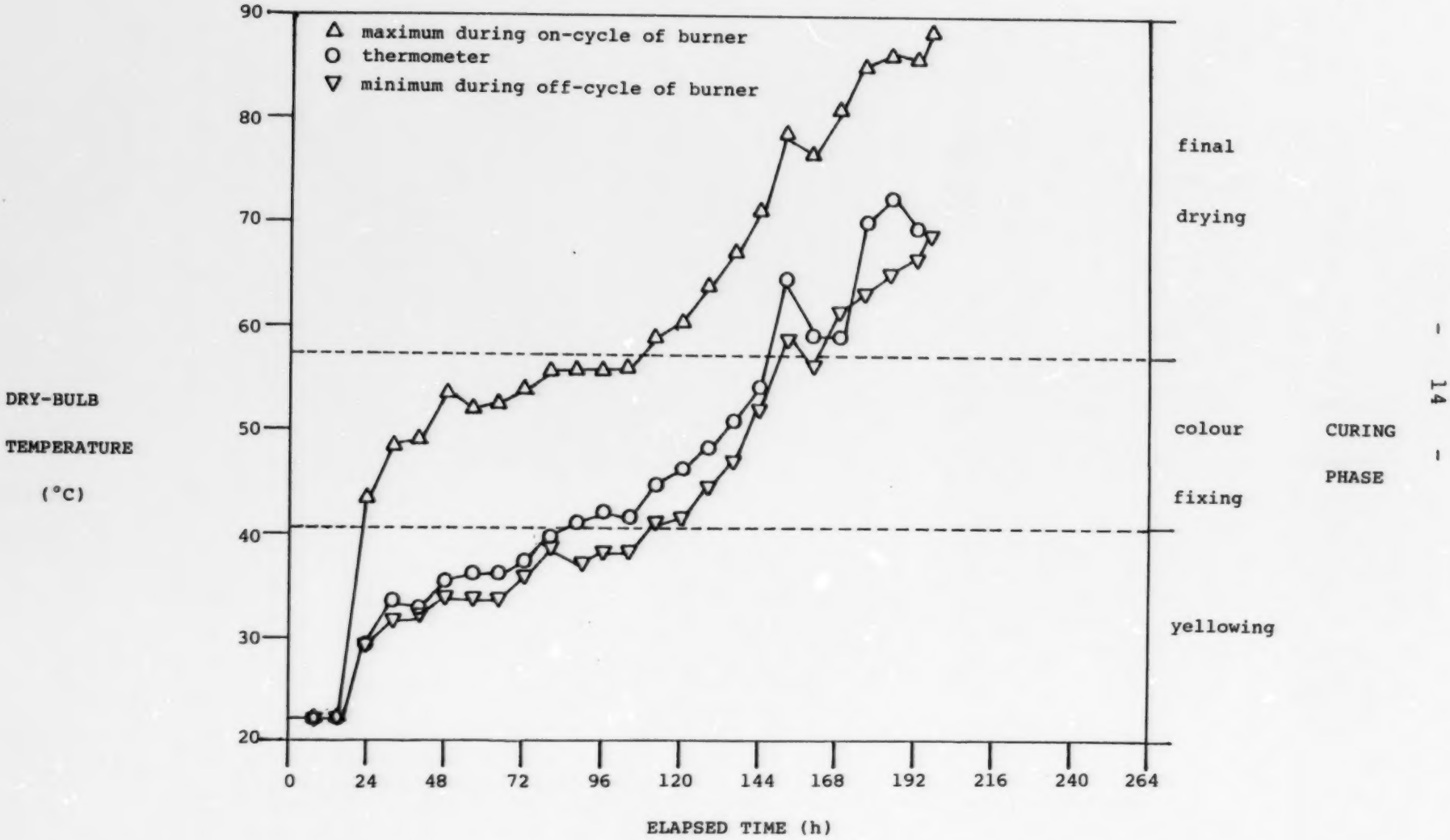

Figure V: Temperature History - Cure II Control Kiln

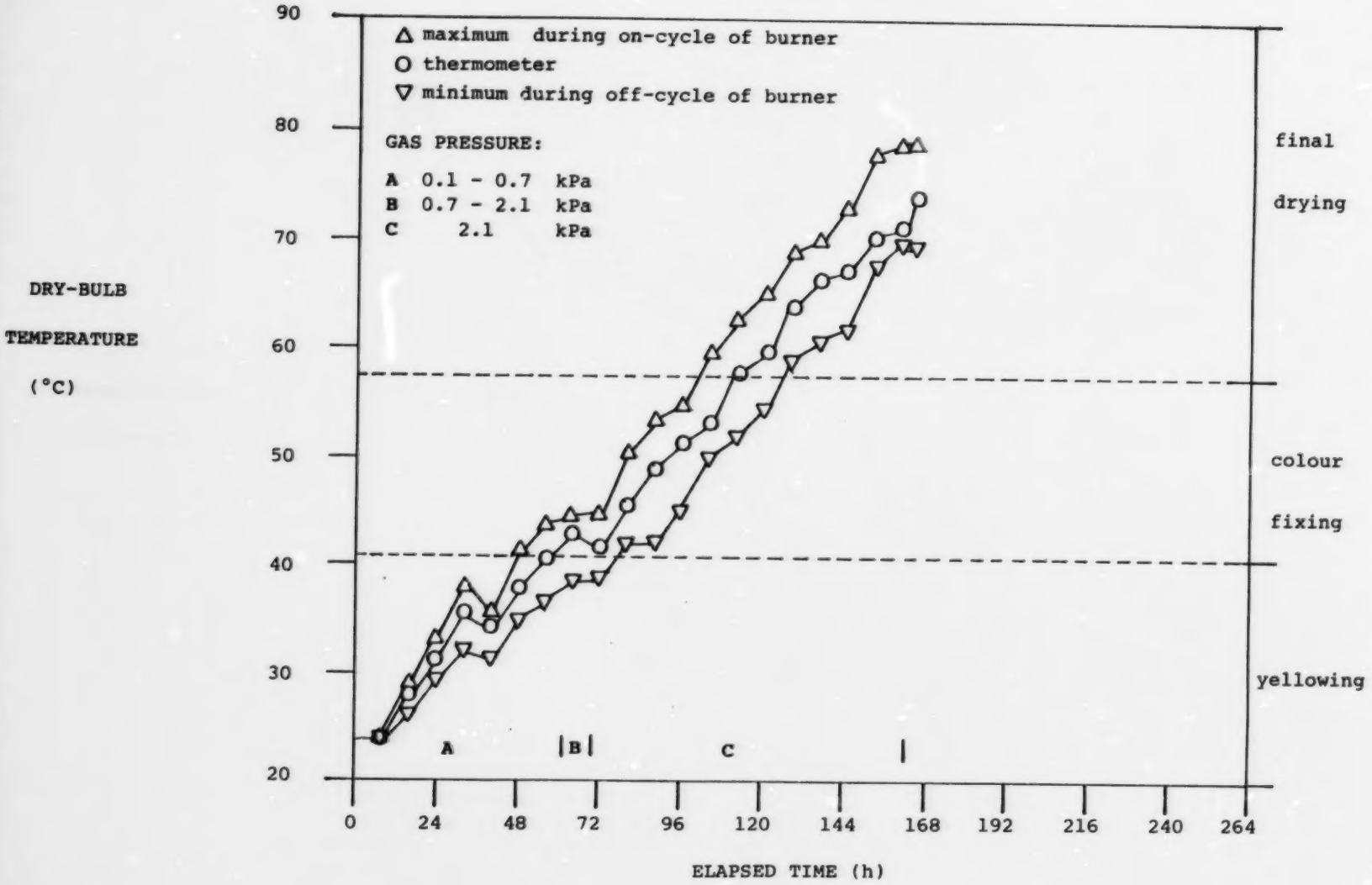

Figure VI: Temperature History - Cure III Test Kiln

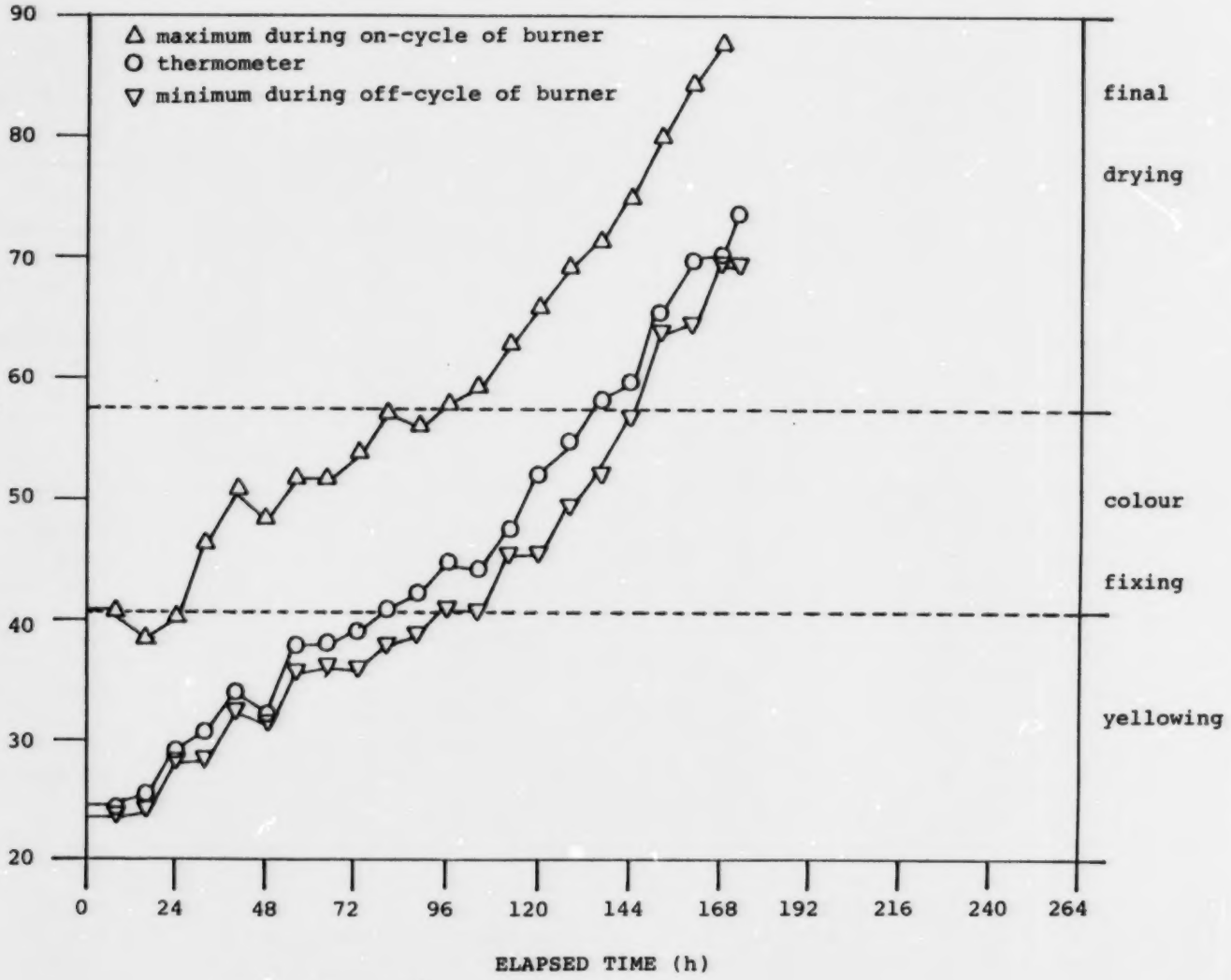

Figure VII: Temperature History - Cure III Control Kiln

Figure VIII: Summary of Temperature, Burner On-Time and Fuel Energy Input Data

CURE	ELAPSED CURING TIME (h)	DRY-BULB TEMP. RANGE MEASURED WITH LIQUID-IN-GLASS THERMOMETER (°C)	ACCUMULATED ON-TIME OF BURNER PER HOUR (minutes)	FUEL ENERGY INPUT (MJ/h)	ELECTRONIC DRY-BULB TEMPERATURE RISE Low (C°)	ELECTRONIC DRY-BULB TEMPERATURE RISE high (C°)
SET I						
Test kiln	0.0-28.5	25.6 - 32.2	20.0	259	3.3	5.0
	28.5-66.1	32.2 - 40.6	28.6	295	3.9	5.6
	66.1-97.5	40.6 - 44.4	29.2	368	5.0	6.1
	97.5-101.0	44.4 - 46.7	36.0	419	6.1	6.1
	101.0-115.8	46.7 - 53.9	34.9	511	7.2	7.8
	115.8-162.4	53.9 - 73.9	32.2	640	7.8	10.0
Control kiln	0-75.1	25.0 - 40.6	9.4	792	N.R.*	N.R.
	75.1-120.8	40.6 - 57.2	21.5	792	N.R.	N.R.
	120.8-172.3	57.2 - 72.8	22.1	792	N.R.	N.R.
SET II						
Test kiln	0.0-43.0	27.2 - 38.9	12.7	290	4.4	5.6
	43.0-72.6	38.9 - 40.6	22.1	339	5.0	6.1
	72.6-92.4	40.6 - 47.2	36.7	422	7.2	7.2
	92.4-173.5	47.2 - 71.1	35.6	624	8.9	11.7
Control kiln	0.0-86.2	25.0 - 40.6	7.6	792	14.4	20.7
	86.2-144.5	40.6 - 57.2	20.6	792	17.8	21.7
	144.5-194.9	57.2 - 72.8	29.0	792	19.4	21.7
SET III						
Test kiln	0.0-61.5	25.6 - 40.6	16.2	318	3.3	6.7
	61.5-70.9	40.6 - 41.7	16.6	474	6.7	6.7
	70.9-162.4	41.7 - 73.9	29.1	630	8.9	12.2
Control kiln	0.0-72.7	24.4 - 40.6	4.7	792	14.4	20.0
	72.7-125.2	40.6 - 57.2	18.1	792	17.2	20.0
	125.2-173.5	57.2 - 72.8	27.3	792	18.3	20.0

*N.R. - not recorded

Figure IX: Curing Fuel Energy Comparison

Cure	Stalk Position	Length of Cure (h)	Natural Gas Consumed (m^3)	Saleable Tobacco (kg)	Energy Consumption MJ/kg*	Difference* %
SET I						
Test kiln	seconds	163	930	946	37.1	+1.6
Control kiln	seconds	173	1001	1000	37.7	
SET II						
Test kiln	fourths	173	1114	1699	24.7	+1.6
Control kiln	fourths	195	1176	1769	25.1	
SET III						
Test kiln	under-tips	163	925	1794	19.4	-10.2
Control kiln	under-tips	174	888	1898	17.6	

*MJ/kg - megajoules of fuel energy consumed per kilogram of saleable tobacco @ 37.7 megajoules per m^3 of natural gas

*Difference % - percentage of fuel saved by the test kiln, ie:
Set I cures $\left((37.7 \text{ MJ/kg} - 37.1 \text{ MJ/kg}) \div 37.7 \text{ MJ/kg}\right) \times 100 = +1.6\%$

Figure X: Summary of Tobacco Grades

	Bright (kg)	Dark (kg)	Green (kg)	Red (kg)	Total Cured Mass (kg)
Test Kiln - 3 cures	2747 (61.9%)*	1336 (30.0%)	336 (7.6%)	20 (0.5%)	4439
Control Kiln - 3 cures	3511 (75.2%)	903 (19.3%)	209 (4.5%)	45 (1.0%)	4668

*percentage of total mass cured